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A Novel LA-MFO Technique based Vehicle to Grid Control Mechanism for Automatic Generation Control in Deregulated Power System

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Abstract: This manuscript introduced a new LA-MFO Technique based Vehicle to Grid (V2G) control mechanism for the automatic generation control (AGC) in deregulated power system. For centralized AGC control, a two-Area Deregulated Power System (TADPS) under bilateral contract, unilateral contract, and contract violation are analyzed. The proposed method is the joint execution of Lichtenberg algorithm (LA) and moth flame optimization (MFO) algorithm. Here, the updation process of LA is done by utilizing the MFO method. Therefore, it is called as LA-MFO algorithm. The proposed method is extended to model the Fractional Order proportional integral (PI) derivative (FOPID).The integral time of absolute error is considered as objective function in order to design the gain of optimum controller. Hence, the FOPID is modeled for the procurement of AGC and load following services and the effectiveness of FOPID in the TADPS is investigated by incorporating an Electric Vehicle with V2G control mechanism. The proposed method is executed in MATLAB site to guarantee its performance..

***Keywords*:** *Vehicle to Grid, automatic generation control, Lichtenberg algorithm, Fractional Order PID controller, moth flame optimization algorithm, controller gains, integral time absolute error.*

1. Introduction

During standard deviation condition, the plug-in Hybrid Electric Vehicles (EVs) (PHEVs) highly minimizes the fossil fuel consumption by utilizing the amount of charge stored in the battery [1]. The PHEVs are also capable to minimize the emission of CO2. Considering these vehicles, there are two types of services. One is named as G2V function in which the vehicle battery is charged from an electrical grid with a plug. The second function is named as Vehicle-to-grid (V2G) service, in which the vehicle discharges into an electric power grid during parking period. V2G regulation involves potential features and implementation issues. The function of Vehicle-to-grid control mainly depends on deviation control of average battery State of Charge (SOC) [2, 3].Generally, the AGC plays a vital part in huge scale multi-area interconnected power systems for controlling system frequency as well as tie-line powers(TLPs)[4-6]. The generating unit frequency is influenced by sudden disturbance that results in low active power compared to power demand. Due to this reason, the system frequency is highly deviated from the defined values and it is considered as unwanted. Therefore, AGC concept is utilized to mitigate the frequency deviation (FD) and maintain the TLP in its defined value [7-10]. However, it is difficult to achieve constant frequency through the speed governor alone. So, it is necessary to develop a control system to neglect the impact of unexpected load changes and improve the frequency in defined value. By accepting the principles and operations of deregulated market, the electric power undergoes the restructured environment condition. The competition with different companies has started in order to enhance the effectiveness and minimize the power cost. Few reorganized rules and economic incentives are developed by the government to manage power industry [11, 12]. These reorganized rules are called de-regulation. The open market system includes different companies called generation companies (GENCOs), transmission companies (TRANSCOs), Independent Service Operators(ISO) and distribution companies (DISCOs). Here, the auxiliary service is considered as a challengeable process for managing the electrical system consistency and safety [13-15]. This manuscript proposes a new LA-MFO technique based vehicle to grid control mechanism for automatic generation control in deregulated power system. The proposed Lichtenberg is defined as optimization algorithm that depends on the idea of radial propagation of intra-

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cloud lightning. The position updation of the LA is done by the Moth Flame Optimization algorithm therefore, it is known as LA-MFO algorithm. Rest of the manuscript is organized as, section 2 reviews the recent research work, section 3 describes the modelling of proposed Power System, section 4 describes the proposed LA-MFO Algorithm, section 5demonstrates the results and discussion and section 6 concludes the manuscript.

1.1. Recent Research work: A Brief Review

Several works existed in the previous literature based on Automatic Generation Control in Deregulated Power System using different methods and features. Few of them were explained here.

Sariki and Shankar [16] have introduced an optimum cascaded 2-degree of freedom PIintegral (2DOF(PI)) as well as proportional derivative with filter (PDF) (CC-2DOF (PI)-PDF)controller for the load frequency control (LFC) device. Here, the introduced controller increased the DOF and mitigated the disturbance using different dynamics. By utilizing an opposition based volleyball premier league algorithm, the control parameters were optimized. The LFC mechanism was implemented at 2-area thermal hydro gas restructured power system. For more realistic investigation, the thermal system was available in every area, such as generation rate constraints (GRC). To verify the improvement of power system inertia, an accurate modelling of inertia emulation strategy (IES) and High voltage direct current(HVDC) tie-line were introduced.

For an interconnected hybrid power system during the deregulated structure, Sharma et al. [17] have presented an Improved Frequency Regulation (IFR). Here, the presented system involves biogas plant, distributed generation and thermal power system. The analysis of Renewable Energy Sources (RES) was done through distributed generations system with the power generation of solar and wind. For investigating the system, a suitable non-linearity's were coordinated with thermal and biogas system. To manage the uncontract demand, electric vehicle was employed. The combined execution of Linear Active Disturbance Rejection Control (LADRC) and hybridized fuzzy-Proportional Integral (FPI) were presented for IFR. Further, a novel method called Quasi-Opposition based Artificial Electric Field Algorithm (QO-AEFA) was presented to attain optimum gain parameters. A pertinent performance analysis was taken place. To find the effectiveness of presented system, a comprehensive investigation and combination of presented controller with different controllers were executed. The trustworthiness of presented controller was guarantee through sensitivity analysis. Hannan et al. [18] explained the impact of electric vehicle, which affects the market, also the vehicle to grid (V2G) technology attained lots of attention. The mobile storage device in an electric vehicle was utilized to help load balancing in the power grid. The development of electric vehicle involves several advantage and disadvantage on grid, such as, voltage, load leveling, smooth integration of renewable energies, frequency regulation, peak load shaving, reactive power compensation. Here, the challenges, opportunities and EV technologies in vehicle to grid connecting system were investigated.

Yumiki et al. [19] have developed the system level model for auxiliary service (AS) development to control electric power grids with in-vehicle batteries, likely to use EVs. Primary frequency regulation on transmission phase and voltage amplitude regulation on distribution phase were developed. A new physics-based model was explained for evaluating and generating the influence of partial temporal charging or large population charging of electric vehicles to the distribution grid. The efficiency of autonomous design of vehicle to grid was investigated with numerical simulation model. Gamil et al. [20] have presented a multi-objective power scheduling of residential microgrid (MG), includes photovoltaic, battery energy storage system (BESS), wind generator (WG), electric vehicles. Maximizing the count of electric vehicle provides a huge burden for electrical grid. For controlling plug-in-EVs of charging and discharging provides comparison of two energy management methods, like load base control (LBC) and renewable base control (RBC).The comparative analysis of 4 sizing states of residential load guarantees the feasibility of economic and environmental feasibility of combining EVs into MGs. Charging and discharging BESS by considering the prices of Time-of-use (ToU)and electric vehicle power were achieved through the control technique. Thus, the comparison among 2 optimization algorithms was done to check the effectiveness of control technique.

1.2. Background of the research work

The researchers over the world developed different control techniques and optimization to study about the limitations of AGC. The concept of optimum control theory, Proportional-Integral, Integral, Integral-Double Derivative, Proportional Integral Derivative (PID), Proportional Integral Double Derivative and Fractional Order PID were analyzed for an Automatic Generation Control problem. For multi-area power systems, the Genetic Algorithm (GA) and the multi-objective optimization problem (MOP) were utilized to tune the proportional integral controller. At 2-area interconnected thermal power system, an optimization method of Artificial Bee Colony (ABC) was implemented to investigate the dynamic performance of automatic generation control. The Differential Evolution (DE) based on controller of Proportional-Integral Derivative for multi-area multi-source power system was developed. The survey shows most of the works are controlled by reheat thermal and hydro plants but it pays less attention only in diesel generating units and wind. Hence, it is known as utilization of non-conventional source and it is very important in the power system. The performance is mostly based on controller structure, then the optimization methods are developed to enhance the parameter controller. Therefore, the classical methods for employing the optimal gain of controllers fails to provide optimum solution to solve harder constrained issues with high count of variables. Hence forth, introducing and executing the high performance of heuristic optimization method to real-world problems are needed. The above limitations are inspired to do this work.

2. Materials and Methods

This section explains the Two area system with V2Gportrays on fig 1.Eachincorporated to BEV at deregulated power system along with bilateral contracts. When the AGC capacity is not enough, the V2G-based BEVs are used for compensating unequal real powers at every region. For simulation analysis, a 2-area interconnected power network is considered using BEVs. So, every area is composed of thermal units, BEV and load [21-23]. Due to its slow dynamic response, the thermal generator cannot compensate adequately because of fluctuation in the load. When there is an inadequate capacity, the rapid dynamic response of BEVs based on vehicle batteries compensates the real power imbalance of the system. The BEV's dynamic response is more instantaneous than the thermal generator's governor. Here, the objective function is the Integral time absolute error (ITAE) and it is expressed below,

$$J_{ITAE} = \int_{0}^{T_{sim}} \left\{ |\Delta f_1| + |\Delta f_2 + |\Delta P_{tie}|| \right\} t dt \quad (1)$$

A count of generation companies (GCO) are defined as count of rows and distribution companies (DCO) is same as count of columns in DISCO participation matrix (DPM) in power system. Load sharing among each DCO and GCO is defined through every entity in DISCO participation matrix. The deregulated power system includes 2 GCOs and 2 DCOs in every area. GCO1, GCO2, DCO1, DCO2 are belong to area 1 and GCO3, GCO4, DCO3; DCO4 are belong to area 2. The DISCO participation matrix or 2-area 4 unit power system is represented below,

$$DPM = \begin{vmatrix} cpf_{11} & cpf_{12} & cpf_{13} & cpf_{14} \\ cpf_{21} & cpf_{22} & cpf_{23} & cpf_{24} \\ cpf_{31} & cpf_{32} & cpf_{33} & cpf_{34} \\ cpf_{41} & cpf_{42} & cpf_{43} & cpf_{44} \end{vmatrix} \quad (2)$$

here the contract participation factor is represented as cpf .

The diagonal elements specify local demands and OFF diagonal elements specifies contract of DCO in 1area along GCO of another area at DISCO participation matrix.

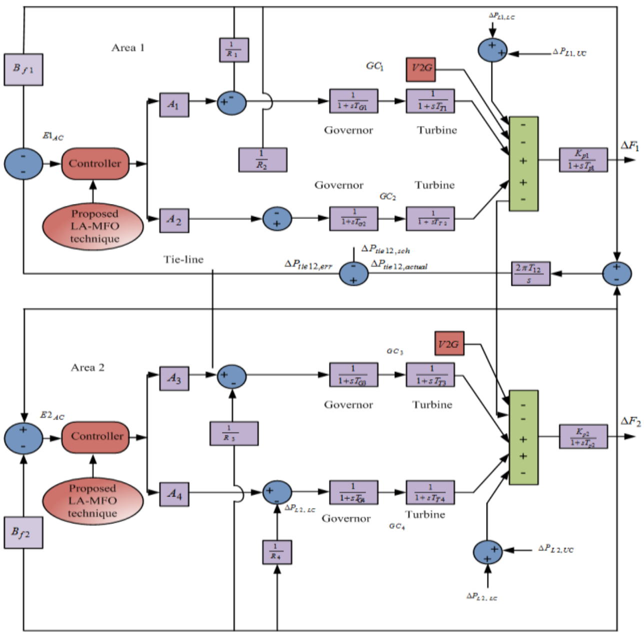

Fig 1: Two area system with V2G

2.1.V2g Control Mode

Electric vehicles are integrated with energy sources and power electronics to generate a 50 Hz AC power supply, whether they are operated by batteries, fuel cells, or hybrid fuels. This electricity is called as "Vehicle to Grid" power or "V2G" if it is routed from EVs to power lines. Vehicle-to-grid power systems expedite the adoption of battery-powered, hybrid, and fuel-cell automobiles. Considering their drive systems supply, the key ingredients of AC power generation, electric vehicles can be employed as energy sources when static. The utilization of stationary vehicles provides the positive net source of revenue and a significant economic incentives to own EV [24-26].The services offered by these systems include backup power for business and residences, meeting peak demands during peak hours and auxiliary service support, etc. Fig 2 shows the Vehicle –to –grid system function.

In the first case, the vehicles are powered from the grid and it also pumps into the grid during idle hours. Power flow from Grid to the vehicle is shown in Blue and Vehicle to Grid power flow is shown in Red. In the second and third cases, the vehicle is powered by conventional fuels, like gasoline, Hydrogen, or fuel cells. It also pumps the power back into the grid during idle hours.As cars and light-duty vehicles start a transformation into electricity powered by batteries, motors or fuel cells, synergistic interaction between these vehicles and the electricity grid is possible. Even if only a small fraction of vehicles is harnessed to produce revenue, both the power grid and the vehicle owners get benefited. The emergence of electric, hybrid, and fuel-cell vehicles creates possibility that parked vehicles become value-creating resources. A large-scale electric power generation tool is generated by connecting these vehicles to the electricity grid. During low demand periods, the vehicles are charged and supply electricity to the grid during the times of demand. On the whole, a large number of vehicles reflect substantial power generation.

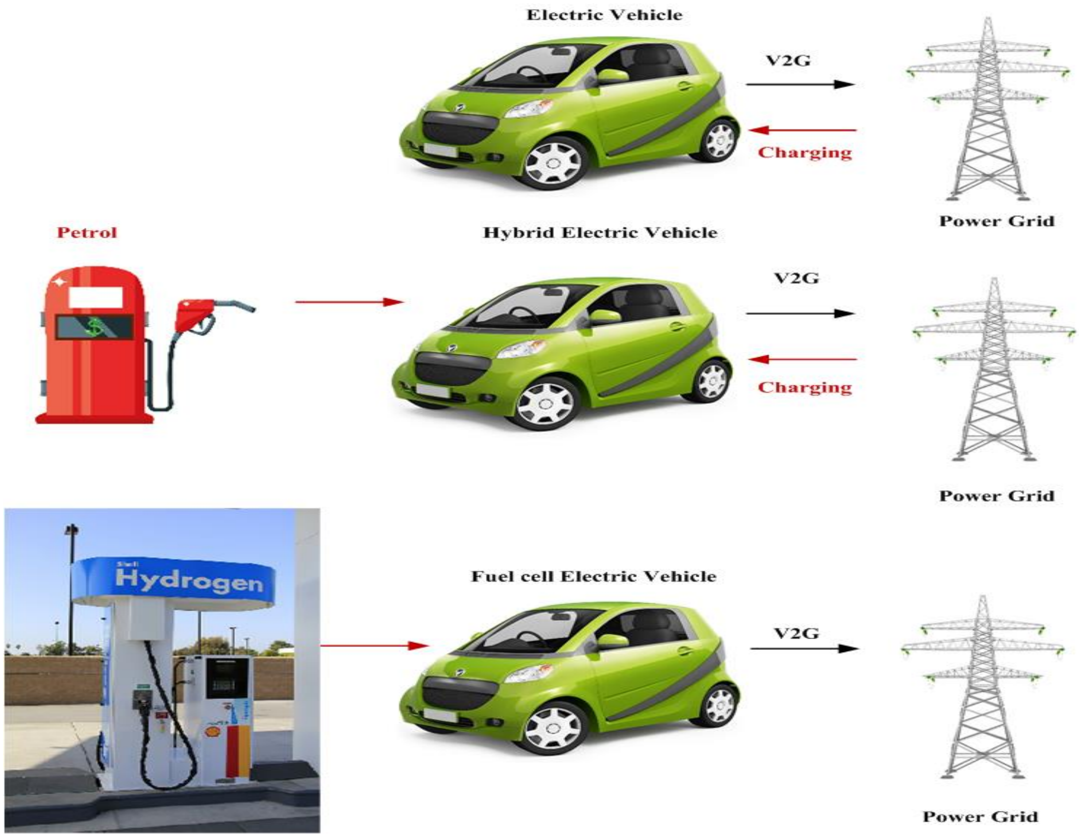

Fig 2: Vehicle- to - Grid Function

2.2. Application of V2G Control Mechanism for AGC

V2G is the most popular EV integration technology in the smart grid. The evolutionary techniques applied for the smart grid activities enable the electric vehicles to enhance the management of the supply grid. The V2G technology enables distributed renewable generation, thereby improving network reliability and performance, leading to mutual advantages. The V2G allows electric vehicles to act as energy storage system for distribution. There are two key connections needed for the implementation of V2G.The first one is the connection for the power flow among the grid and EV. Then, the second one is logic control that defines the quantity and direction of power flow that is allowed between EV and the grid.V2G technology promotes an integrated grid network by peak load leveling and voltage management by introducing effective optimization and control techniques [27, 28]. The V2G device uses EVs' energy storage as a backup source for renewable energy sources, thus allowing voltage and frequency control. Running plug-in Hybrid EVs for auxiliary services, like regulation and spinning reserves are operated through Independent Service Operators (ISO) and they are considered as most profitable. Regulation changes the grid frequency by balancing generation with demand; also the spinning reserve offers additional capacity for generation. V2G can be used to compensate the supply-load imbalance, which is reflected on system frequency and it aids to alleviate the deviations on frequency through its droop control characteristic as shown in fig 3.

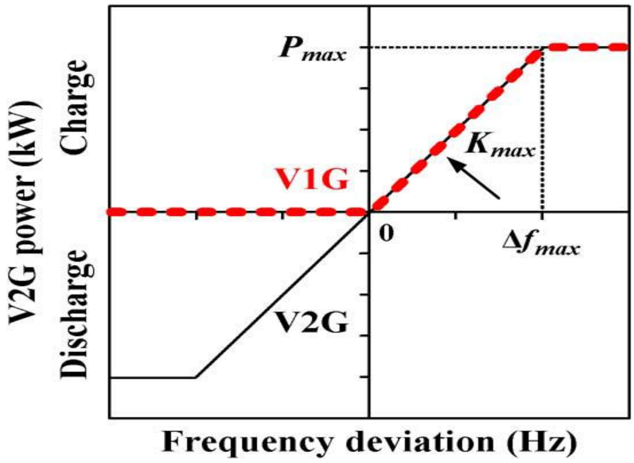

Fig 3: Droop control characteristic

The power P_{V2G} support by $V2G$ control is expressed by,

$$P_{V2G} = \begin{cases} K_{V2G}\Delta f \left(|K_{V2G}\Delta f| \leq P_{\max} \right) \\ P_{\max} \quad P_{\max} < |K_{V2G}\Delta f| \end{cases} \tag{3}$$

where K_{V2G} defines the gain tuned by considering the $V2G$ effect and battery State of Charge (SOC) and $P_{\max}$ denotes the maximum $V2G$ power. If state of charge is close to full/empty, a high-power charging or discharging is not introduced to avoid overcharging /discharging. The SOC is considered to be complete or empty under long-term vehicle to grid period, since the value of mean frequency variation is not consistently 0, this leads to battery loss. To avoid this problem, a balance control is established to estimate an accurate SOC and it is expressed as,

$$K_{V2G} = K_{\max}\left\{1 - \left(\frac{SOC - SOC_{low(high)}}{SOC_{\max(\min)} - SOC_{low(high)}} \right)^n \right\} \tag{4}$$

where $K_{\max}$ is the maximum gain of $V2G$ .The values of n , SOC_{low}, SOC_{high}, $SOC_{\max}$ and $SOC_{\min}$ are designed around 50% SOC as shown in fig4.

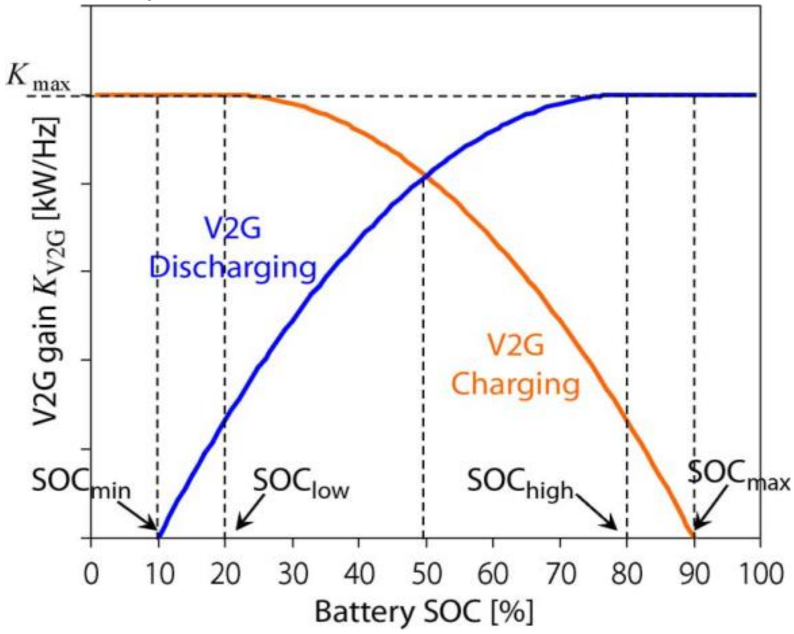

Fig 4: Control and balance of State of Charge of Battery

The $V2G$ control follows a smart charging protocol. When the Frequency variation drops below a minimum level, the maximum discharge for the grid is given immediately. Here, P_{V2G} regulated by tuning K_{V2G} gain against FD based on equations (3) and (4). Here, K_{V2G} is modified among the particular range of State of Charge through the deviation control of State of Charge.

2.3. Mathematical Modeling of FOPID Controllers

The structure of FOPID controller portrays on fig 5. In the FOPID controller, the control parameters K_p, K_i, K_d along with the system variables λ and μ are expressed below,

$$C(S) = k_P + \frac{k_i}{S^{\lambda}} + k_d S^{\mu} \tag{5}$$

The transfer function of FOPID controller defined as $PI^{\lambda}D^{\mu}$ controllers and it can be illustrated as,

$$C_{FOPID}(S) = \frac{u(s)}{err(s)} + k_c\left(1 + \frac{1}{\varsigma_i s} + \varsigma_d s\right) \tag{6}$$

here λ, μ specifies 2 random numbers, K_p specifies Proportional amplification gain, K_i implies integral gain, K_d specifies differential gain, ς_i specifies integral time constant, ς_d specifies differential time constant.

The FOPID is changed in to classical proportional integral derivative controller when $\lambda = \mu = 1$. For practical digital realization, the derivative part is extended using the 1[st]order filter and it reduces high frequency noise.

$$G_{FOPID}(S) = K_c\left[1 + \frac{1}{\varsigma_i S^{\lambda}} + \frac{\varsigma_d S^{\mu}}{\frac{\varsigma_d}{N} S + 1}\right] \tag{7}$$

The FOPID controller is mainly utilized to adjust the dynamics of power system.

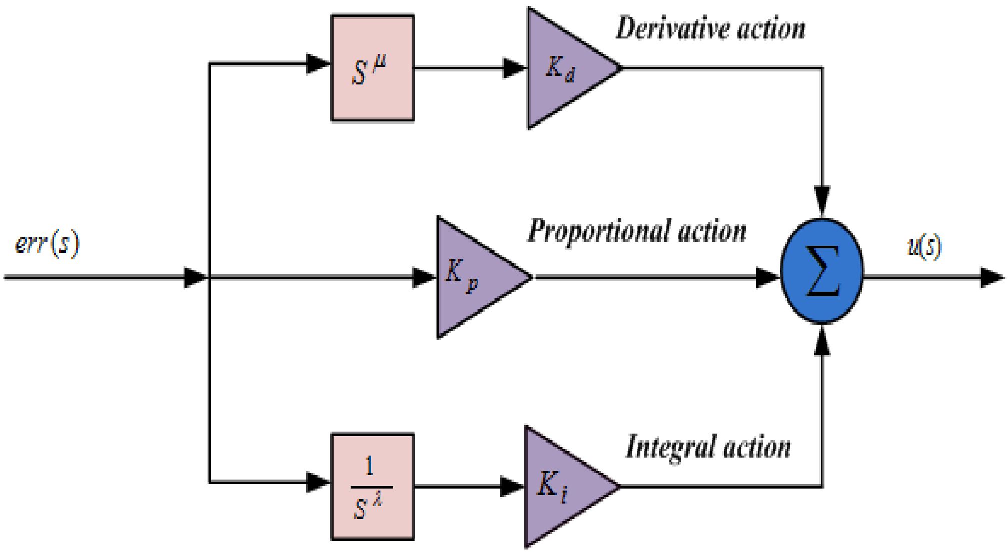

Fig 5: Structure of fractional order PI controller

2.4. Proposed LA-MFO Algorithm

Lichtenberg Figures (LF) describes as optimization algorithm depends on the idea of radial distribution of intra-cloud lightning. This LF is derived from the image and is generated in sky due to lightning. A significant asset is the superior structure of LF. The LOA population is divided into lesser branches using LF. By approximating the y values, the inspection process is improved [29]. An algorithm is used to assign its number to their branch. Here, the position updation of LA is done by MFO algorithm and this algorithm is one of optimization algorithm based on moths' navigation mechanism in night called transverse orientation [30]. Hence, the proposed method is called as LA-MFO algorithm. The steps involved in LA-MFO algorithm portrays on fig 6.

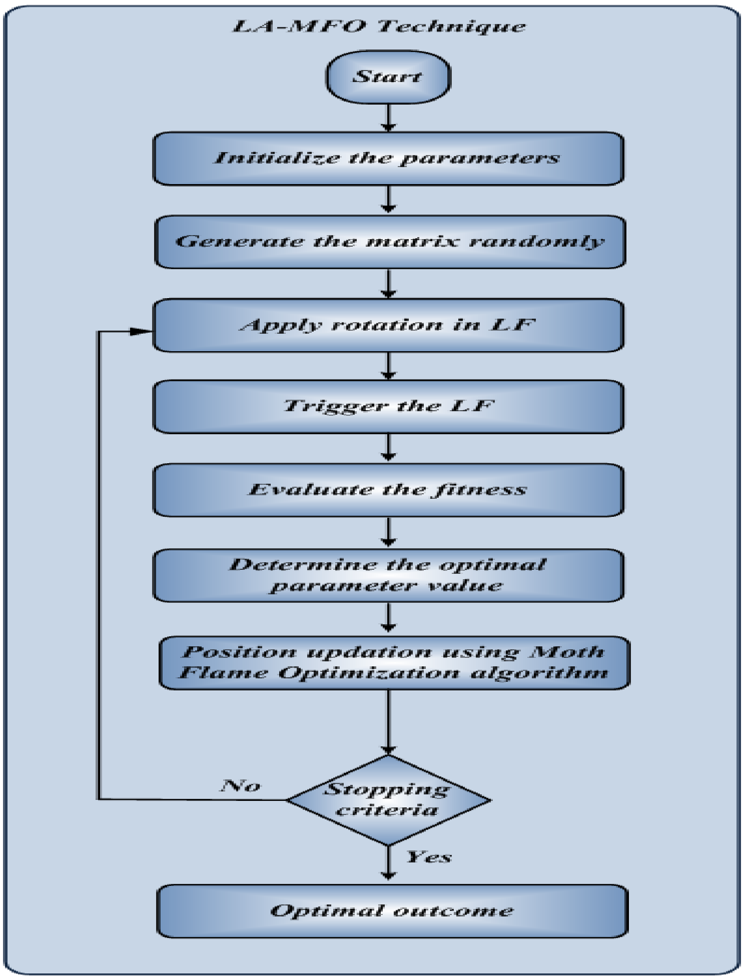

Fig 6: Flowchart of LA-MFO algorithm

Step 1: Initialization

Initialize the power system data and input gain parameters of FOPID controller, such as K_p, K_i, K_d, λ *and* μ.

Step 2: Random Generation

The Lichtenberg figures by utilizing the routine parameter m and the population of Lichtenberg are generated randomly. Thus, it is illustrated as,

$$F(\delta)=\begin{bmatrix} \delta^{11} & \delta^{12} & \cdots & \delta^{1n} \\ \delta^{21} & \delta^{22} & \cdots & \delta^{2n} \\ \vdots & \vdots & \vdots & \vdots \\ \delta^{m1} & \delta^{m2} & \cdots & \delta^{mn} \end{bmatrix} \quad (8)$$

$$\delta = K_p, K_i, K_d, \lambda, \mu \quad (9)$$

Step 3: Apply rotation in Lichtenberg figures

According to the rotation, the next Lichtenberg figures are generated in which reference speed is not equal to 0.

Step 4: Lichtenberg figures Triggering

Trigger the LF for the first time, the optimal point of the previous one is reached. Also, this provides the best fitness

Step 5: Evaluating Fitness

At some point of LF, the fitness is evaluated to determine better optimal value. It is evaluated depends on objective function. The error of objective function is expressed as

$$obj = Min(error) \quad (10)$$

$$error = e_1(t) + e_2(t) \quad (11)$$

$$e_1(t) = ACE_1 = B_1\Delta F_1 + \Delta P_{12} \quad (12)$$

$$e_2(t) = ACE_2 = B_2\Delta F_2 + \Delta P_{21} \quad (13)$$

here, the frequency bias parameters is specified as B_1 and B_2; ΔF_1 and ΔF_2 specifies system frequency deviations(FD)in Hz. Here, ΔP_{tie} denotes change in TLP. When the system underwent small disturbances, the area control errors (ACEs) are utilized actuating signal to mitigate ΔP_{tie} and ΔF to 0 when steady state is attained.

Here, integral time of multiplied absolute error (ITAE) is objective function used to optimize the FOPID controller gain is denoted as,

$$ITAE = \int_{0}^{t_{sim}} \left(|\Delta F_i| + |\Delta P_{tie-i-k}| \right) t.dt \quad (14)$$

From equation(14), the increasing change on frequency of area i denotes ΔF_i. $\Delta P_{tie-i-k}$ defines increasing change on tie-line power connection among area i, k; t_{sim} specifies simulation time range.

Step 6: Position Updation

The position updation uses the MFO algorithm and it is expressed as,

$$Flameno = round\left(N - l * \frac{N - l}{T} \right) \quad (15)$$

here, l defines current count of iteration; N denotes maximal count of flames, T denotes maximal count of iterations. To balance the phases of exploration and exploitation of solution space is achieved by decreasing number of flames.

Step 8: Stopping Criteria

After getting the optimum result, the process is stop otherwise go to step 3. The output of best optimal outcome is expressed as,

$$F(\delta)^{optimal} = \begin{bmatrix} \delta^{11} & \delta^{12} & \cdots & \delta^{1n} \\ \delta^{21} & \delta^{22} & \cdots & \delta^{2n} \\ \vdots & \vdots & \vdots & \vdots \\ \delta^{m1} & \delta^{m2} & \cdots & \delta^{mn} \end{bmatrix}^{optimal} \quad (16)$$

3. Result and Discussion

To establish the efficacy of V2Gmethod for frequency regulation on deregulated power market, a suitable controller is required for the secondary control mechanism. The V2G subsystem is represented in fig 7 is included in the model along with bilateral contracts that exist between the GCO and DCO. The simulation results are tabulated in table 1. The controllers are tuned through the LA-MFO optimization algorithm by minimizing ITAE and a contract violation is also included. The output responses obtained through simulation for both the areas are given in fig 7 to fig 9. The DPM used for simulation is expressed as,

$$DPM = \begin{bmatrix} 0 & 0.3 & 0.25 & 0.2 \\ 0.6 & 0.2 & 0 & 0.2 \\ 0.2 & 0.4 & 0.25 & 0.6 \\ 0.2 & 0.1 & 0.50 & 0 \end{bmatrix} \quad (17)$$

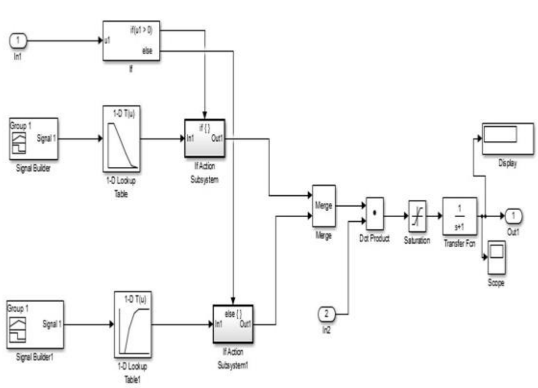

Fig 7: V2G Subsystem

Table 1: Optimized gains

Optimized FOPID Gains	Without V2G	With V2G
K_{p1}	0.1835	2
K_{p2}	1.9999	1.9551
K_{i1}	2	1.9999
K_{i2}	2	1.4548
K_{d1}	0.5264	0.8074
K_{d2}	0.5097	0.6624
λ_1	1.0005	1.0070
λ_2	0.9994	1.0053
μ_1	1.1173	1.1914
μ_2	1.1716	1.2060
ITAE	0.0053	0.0029

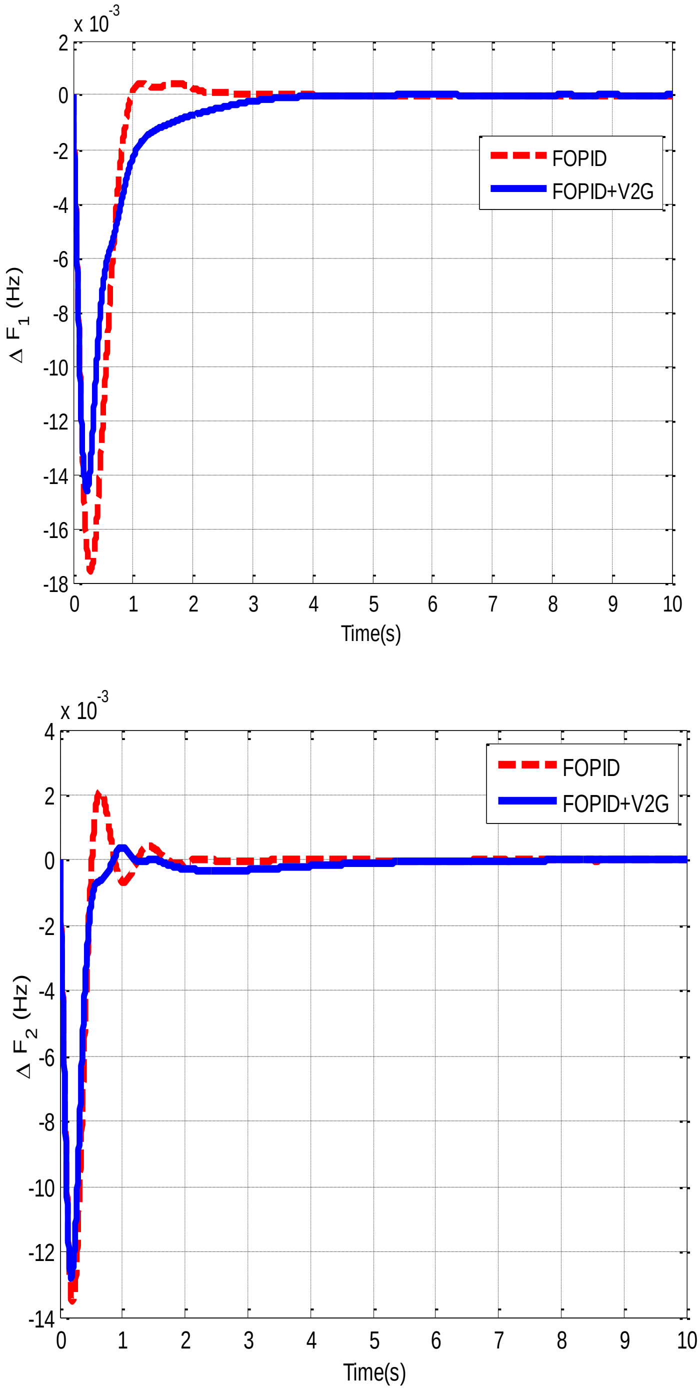

Fig 8: Area-1frequency perturbation

The frequency deviation (FD) recorded in both area1 and area 2 along with the proposed technique based FOPID and without proposed technique based FOPID, V2G control are compared and illustrated in fig8&fig9. Analyzing the time 0.5 to 3 sec is known from the figures that the FD is low for the proposed technique based FOPID with V2G control in both area. From fig8, the FD in area-1 settles down in 4 seconds when FOPID and V2G are included. Undershoot in area-1 frequency is -0.0014 Hz. There is no appreciable change in undershoot and overshoot when V2G is included. From fig9, the transient performance is better in area-2 frequency. The settling time of the area-2 FD is 4 seconds. There is no appreciable change in undershoot. The overshoot is decreased to 0 from 0.002 Hz when V2G is included.Fig10 represents the Tie-Line power perturbation (TLPD). The TLPD of proposed method based FOPID; V2G system is very smooth when V2G is included. The scheduled TLP is 0.00125 puMW.

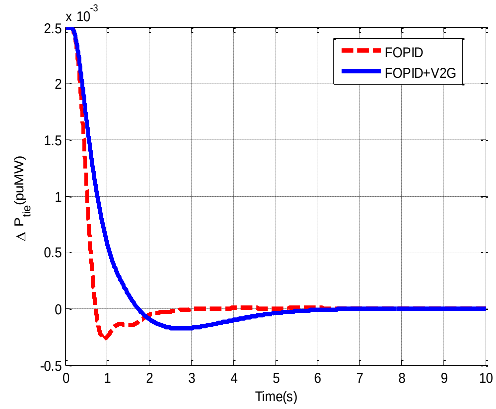

Fig 9: Tie-Line power perturbation (TLPD)

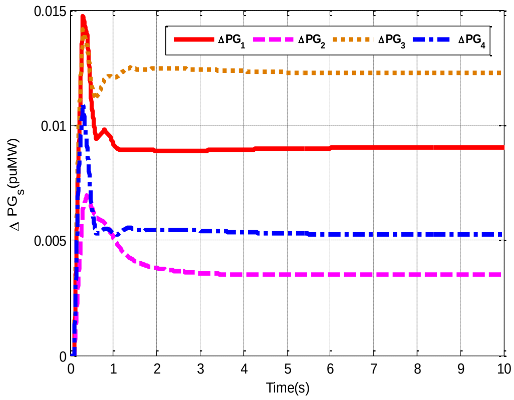

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Fig 10: Power output of Generation Units

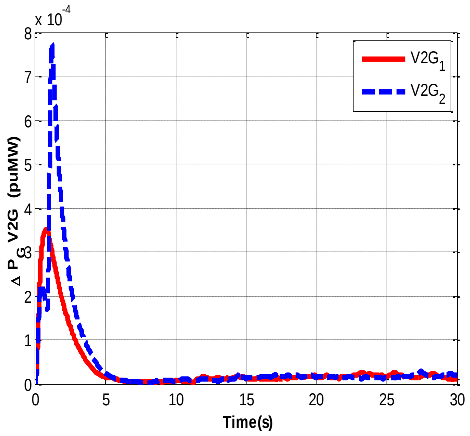

Fig 11: Change in power output of V2G system in Area-1 & 2

The outputs of four generating units are plotted in fig 11. In this fig, the power outputs at steady-state rendered by the four GCOs are, 0.00675, 0.007, 0.01075and 0.0055 pu MW. Fig11 denotes change in power output of V2G system in Area-1 & 2. As seen from the responses, the BEV output changes during a load disturbance so as to supply its real power in both areas. As the frequency drop is more in area-1, also the change on output of V2G in Area-1 is more. Since, the change in frequency at Area-2 is not so large; the change in output of V2G at Area-2 is less. From the output responses, the electric vehicle with V2G control can work effectively in the deregulated two area network that has a bilateral market structure.

3.1. Quantitative Analysis with V2G

From the output responses, the dynamic performance of deregulated system after the inclusion of V2G has been analyzed by examining the values of peak undershoot and over shoot and time taken for the deviation to settle down. These parameters are measured and given in table 2.

Table 2: Performance measures of Frequency variations –proposed FOPID& V2G

	Without V2G			With V2G		
Area	**Settling Time (s)**	**Undershoot(Hz)**	**overshoot(Hz)**	**Settling Time (s)**	**Undershoot(Hz)**	**overshoot(Hz)**
1	4	-0.0017	0.001	4	-0.0014	0
2	4	-0.0014	0.002	4	-0.0012	0

From the above table, it seems that the responses obtained with proposed FOPID is incorporated with V2G control in both areas are better than those without V2G. Even though, the settling times are same with or without V2G, the damping is improved with V2G.

4. Conclusion

The proposed two-area power system having bilateral contracts with violation has been analyzed by including the V2G control scheme in both the areas. The FOPID controller has been employed and the gains have been tuned by the proposed LA-MFO algorithm with ITAE as cost function. The optimized gains have been used for simulation and the resulting frequency variations, TLP deviations and the power output of GCOs are plotted. The performance measures shows that the addition of proposed method based V2G improves the dynamic performance of the system to considerable level during contract violation.

Acknowledgement: None

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